Research Evaluation of Wind Generation, Solar Generation, and Storage Impact on the California Grid

CEC IEPR Staff Workshop

Technologies to Support Renewable Integration

(Energy Storage and Automated Demand Response)

November 16, 2010 Sacramento, CA

Report Prepared for:

California Energy Commission

Public Interest Energy Research Program

CEC-500-2010-010, June 2010

Report published on CEC website in June, 2010

The report describes the new analytical model that KEMA developed to analyze the minute to minute variable of wind and solar renewable resources, the ability of conventional generation resources to the variability, and the role that energy storage can fulfill to assist with the integration of large amounts of renewable resources.

Arnold Schwarzenegger
Governor

RESEARCH EVALUATION OF WIND GENERATION, SOLAR GENERATION, AND STORAGE IMPACT ON THE CALIFORNIA GRID

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
KEMA, Inc.

June 2010
CEC-500-2010-010

Project Objectives

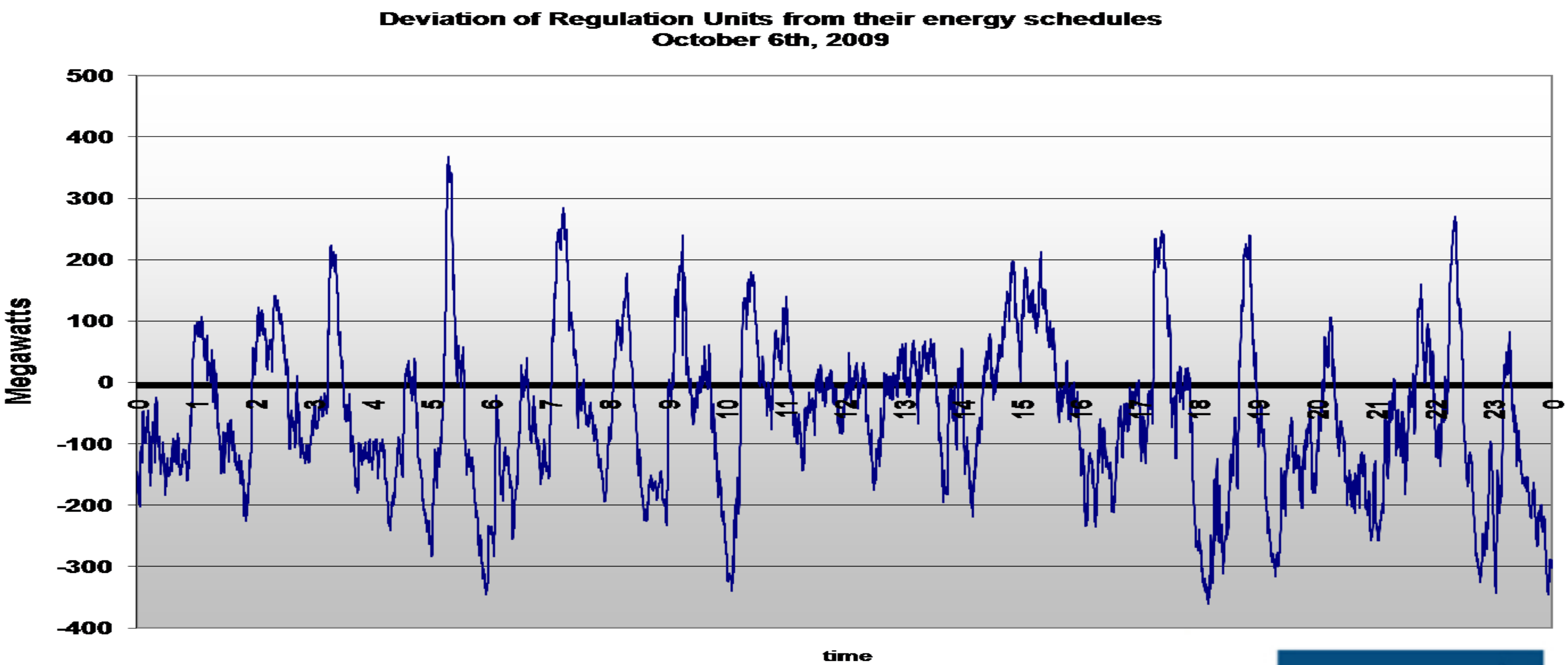
- Evaluate Impact of 20% and 33% Renewable Portfolios on California Grid Operations
  - AGC Performance, Load Following Ability
- Determine Ancillary Services (Regulation, Governor Response) Requirements of 20% and 33% Renewable Portfolios
- Determine Requirements for Use of Large Scale Grid Connected Storage for Ancillary Services
- Evaluate Storage Equivalent of a 100MW Combustion Turbine
- Determine Policy Issues Affecting Storage Development in California

Project Overview

- Research examined the effects of high renewable penetration on intra-hour system operations of the California Independent System Operator (California ISO) control area
- Examined how grid-connected electricity storage might be used to accommodate the effects of renewables on the system
- Utilized KEMA's high-fidelity model (KERMIT) to analyze the effects of planned additions of renewable generation on electric system performance
- Research focused on required changes to current systems to balance generation and load second-by-second and minute-by-minute
- Study also assessed potential benefits of deploying grid-connected electricity storage to provide some of the required components—including regulation, spinning reserves, automatic governor control response, and balancing energy—necessary for integrating large amounts renewable generation.

Context

- Automatic generation control operates the generators that supply regulation services (up and down) every 4 seconds to keep system frequency and net interchange error as scheduled. The *real-time dispatch* buys and sells energy from generators participating in the real-time or balancing market every five minutes to adjust generator schedules to track a system's load changes.



Study Highlights

- Model of California generators, loads and WECC regions
  - Second by second simulation for 24 hours of California system
  - Model of 4 second EMS dispatch of regulation
  - Model of Market dispatch of supplemental energy
  - Model of wind and solar variability – but limited solar data was available

Calibrated to System Frequency Response (Unit Trip) and to System AGC Performance (CPS, ACE PSD)

- Number of days studied was very limited
  - Intensive data collection / validation effort involved
- Results clearly showed that:
  - Energy Ramps in less than 1 hour is going to be a major issue
  - Increased Renewables will Increase regulation needs significantly
  - Large amounts of regulation alone will not solve the problem
  - Energy Storage with 2 hours of capacity or more is an (expensive) solution
  - This simulation tool can be a major asset for renewable integration studies
  - AGC Algorithm development desirable for renewables integration

Time Domain, Problems, and Methods

Harmonics

Protection

Stability

Frequency Response

Regulation

Balancing

Replacement Reserves

Capacity

Economics

1 ms 1 cycle 1 second 1 minute 10 minutes 1 hour 1 day 1 month 1 year

Transient and Harmonics
Analysis
Short Circuit

Governor Response

Statistical Analysis of AGC and Balancing

Spinning and Short Term Reserves

Storage

Replacement Reserves

Emissions Performance

Production Costing
Market Simulation
Expansion Planning

Long Term Generation, Transmission, DSM, and DG Investments

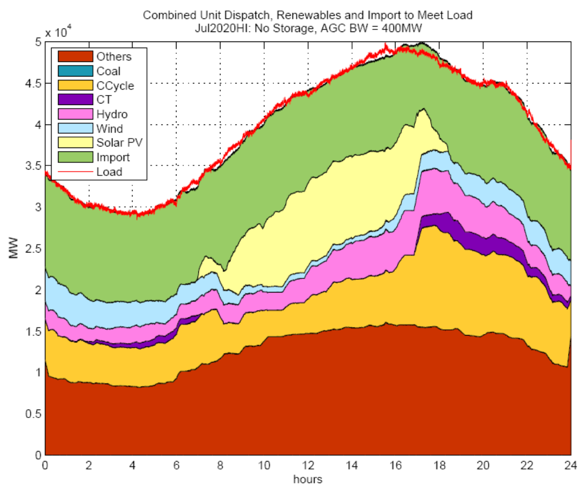
Power Factory
PSSE
DigSilent

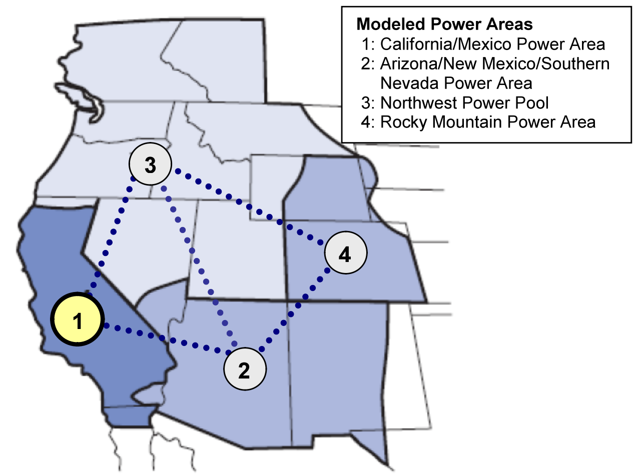
KEMA Simulation Tool

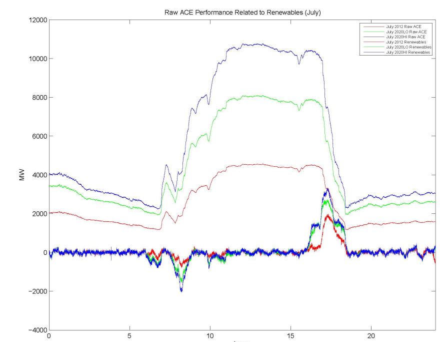
ProMod
GE MAP

KEMA Energy Ecology Model

KEMA Simulation Tool







Generator Trip

Load Rejection

Wind Power Forecast versus Actual

Volatility in Renewable Resources

Standard Inputs:
Load
Plant Schedules
Generation Portfolio
Grid Parameters
Market/Balancing

Scenarios:
Increasing Wind
Adding Reserves
Storage Parameters
Test AGC Parameters
Trip Events

KERMIT
24h Simulation

Generation
- **Conventional**
- **Renewable**

Frequency Response

Inter-connection

Real Time Market

Outputs:
ACE
Power Plant MW Outputs
Area Interchange
Frequency Deviation

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Data Summary

- We have time-series data for the following days, which are used during calibration process:
  - 06/05/2008
  - 07/09/2008
  - 10/20/2008
  - 02/09/2009
  - 04/12/2009

- For simulation of future years: Existing time series were scaled up to reflect the projected capacities in 2012 and 2020.

Plant Capacity in Megawatts

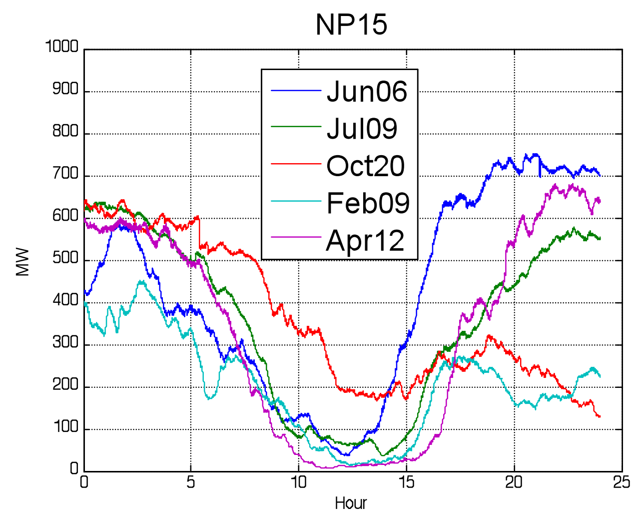
Year	2009	2012	2020 low	2020 high
PV	400	830	3234	3234
CST	400	996	7297	10000
Wind	3000	5917	10972	13000

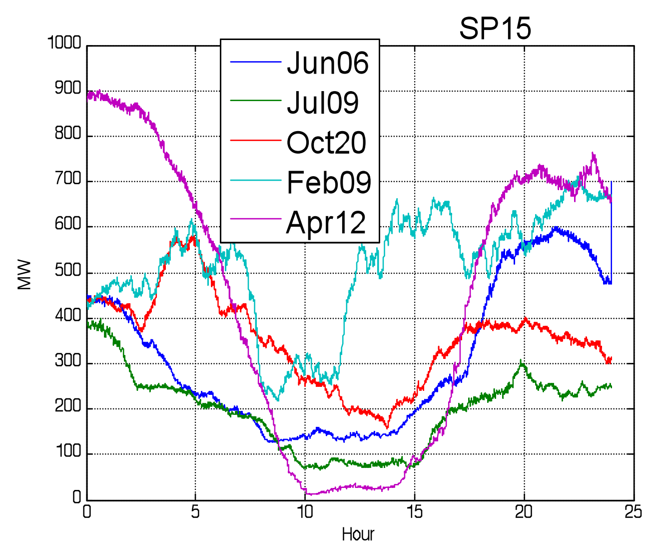
Wind power

- Available from CAISO as time series.
  - Time series of the past (see side graphs), were scaled up according to capacity table
- Appropriate weightings were used to reflect location of future windfarms including wind in BPA Control Area that has to be balanced by CA ISO

Plant Capacity in Megawatts

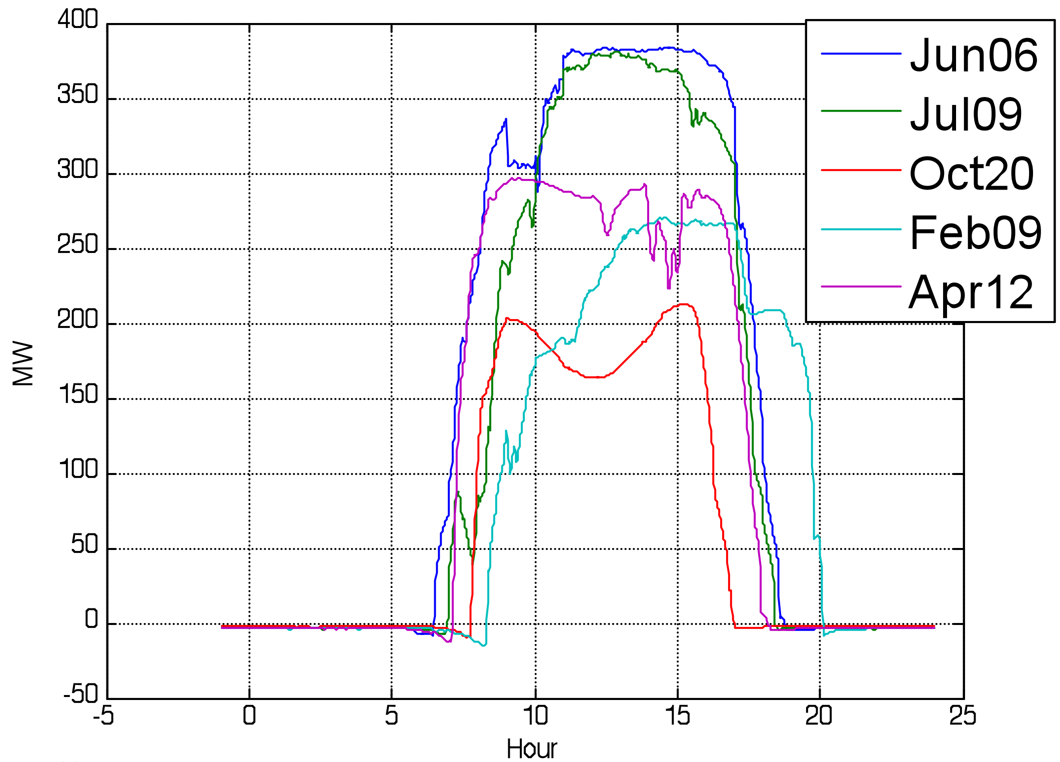
Year	2009	2012	2020 low	2020 high
Wind	3000	5917	10972	13000





Concentrated Solar Thermal

- Available from CAISO as time series
- Afternoon production extended two hours to reflect gas firing
- Scaled up to reflect capacity table
  - Belief is that geographic diversity will be minimal



Plant Capacity in Megawatts

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CST	400	996	7297	10000

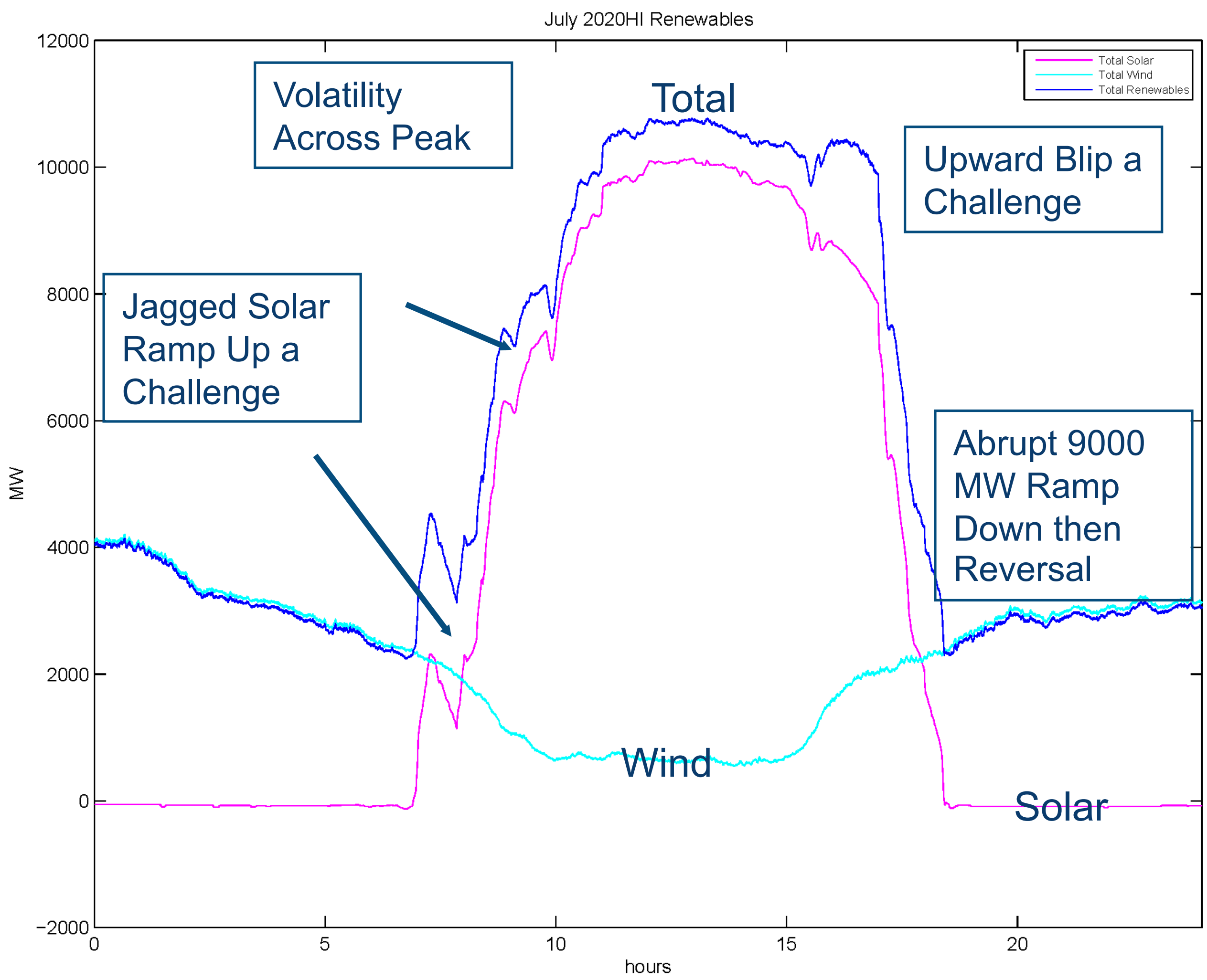
Photovoltaic

- Lacking measurements, we will use simulated time series.
- KERMIT has PV model:
  - Direct inputs are time series for Temperature (degC) and Solar intensity (W/m^2).
    - From NOAA site, we can get these data for selected days for a particular locations in the US.
  - Indirect inputs are related to panel characteristics (electrical and tilt), the surroundings (clouds, abedo)
- The next slide shows simulated time series for a 100MW fictitious PV farm in N. California.
- Such time series will be scaled up for 2012 and 2020, based on the capacity table below.

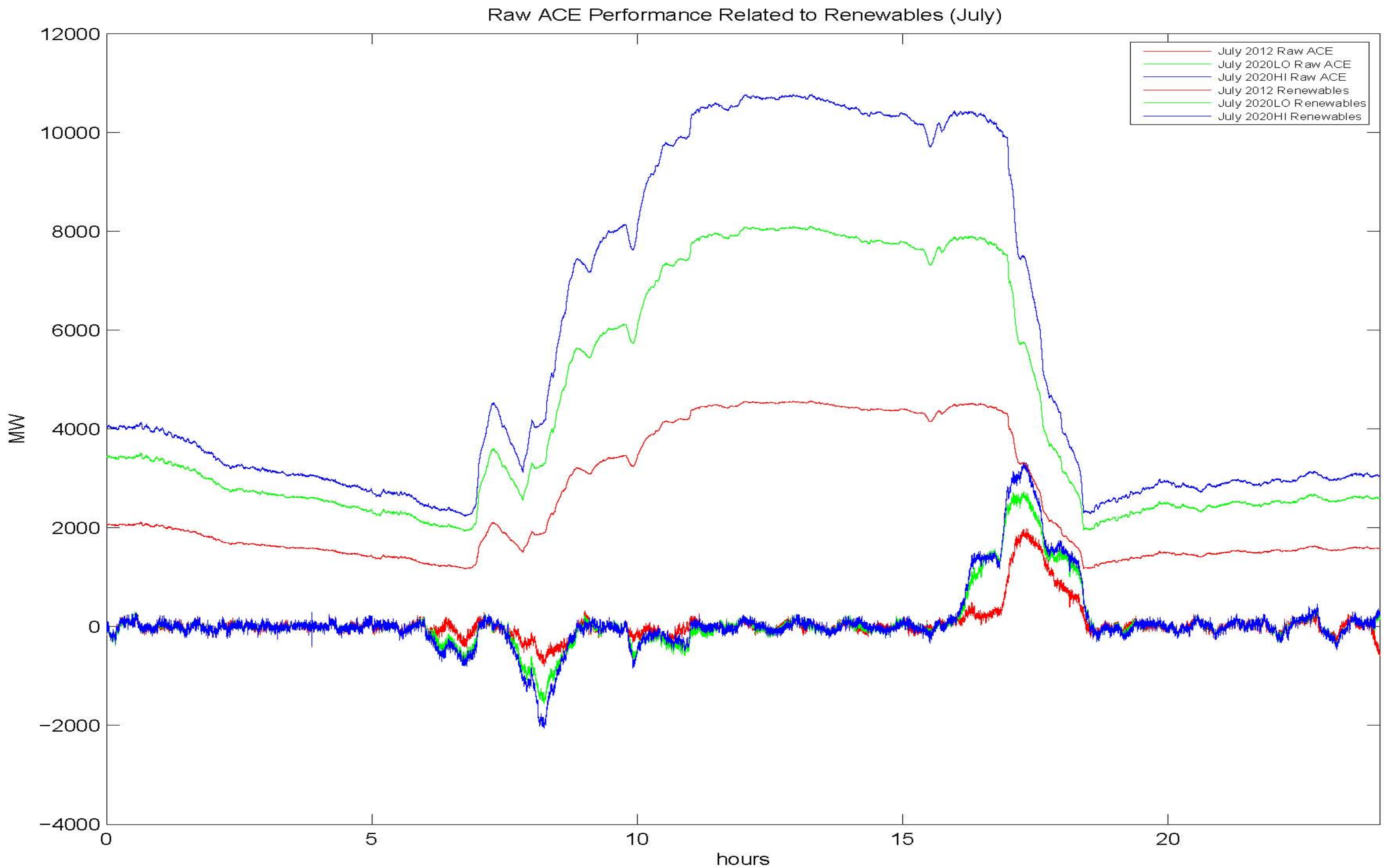
Plant Capacity in Megawatts

Year	2009	2012	2020 low	2020 high
PV	400	830	3234	3234

July Renewables – 2020 High Penetration

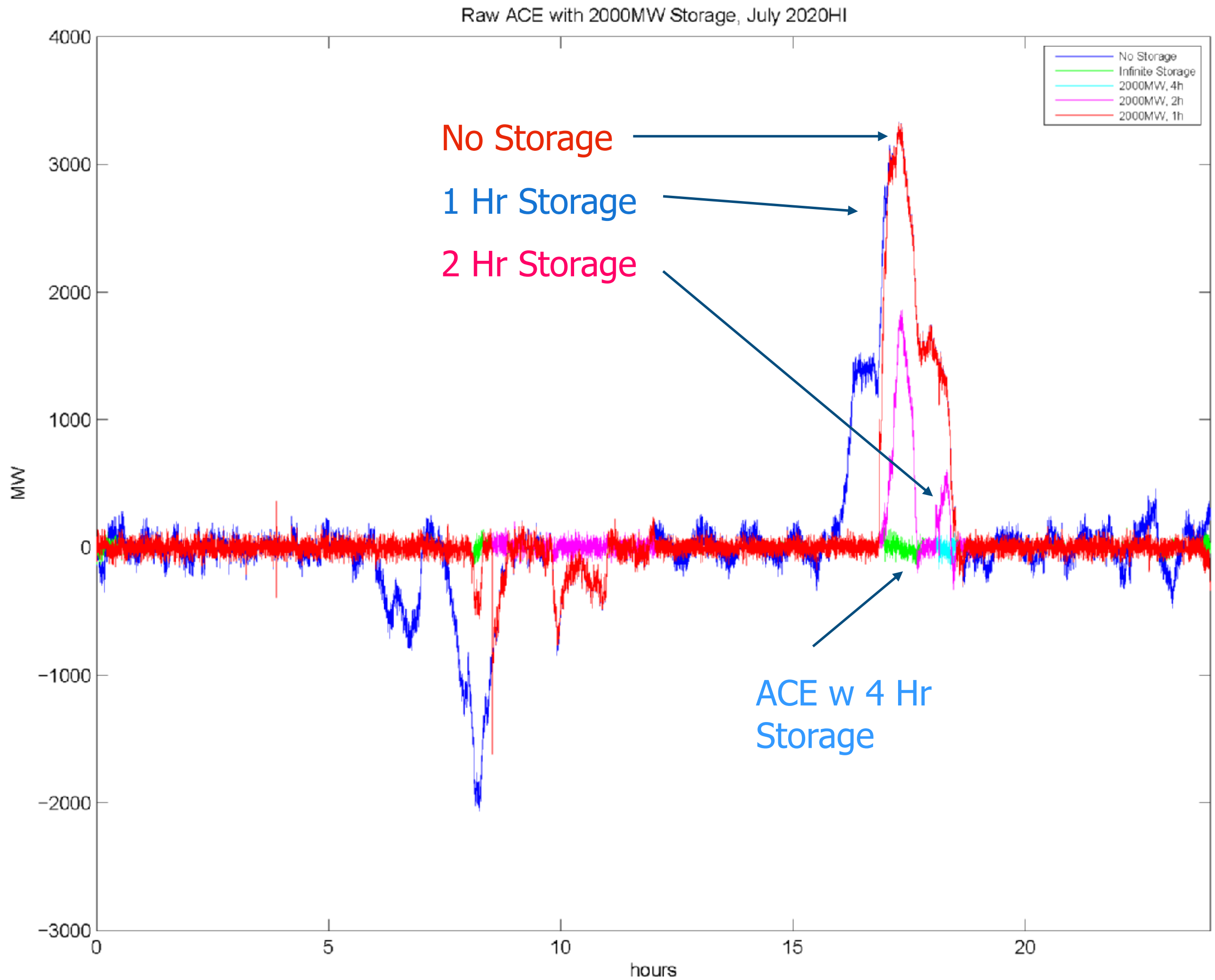


July Day – ACE across renewable scenarios



Evaluating Performance - 2000 MW Storage, July 2020HI Scenario

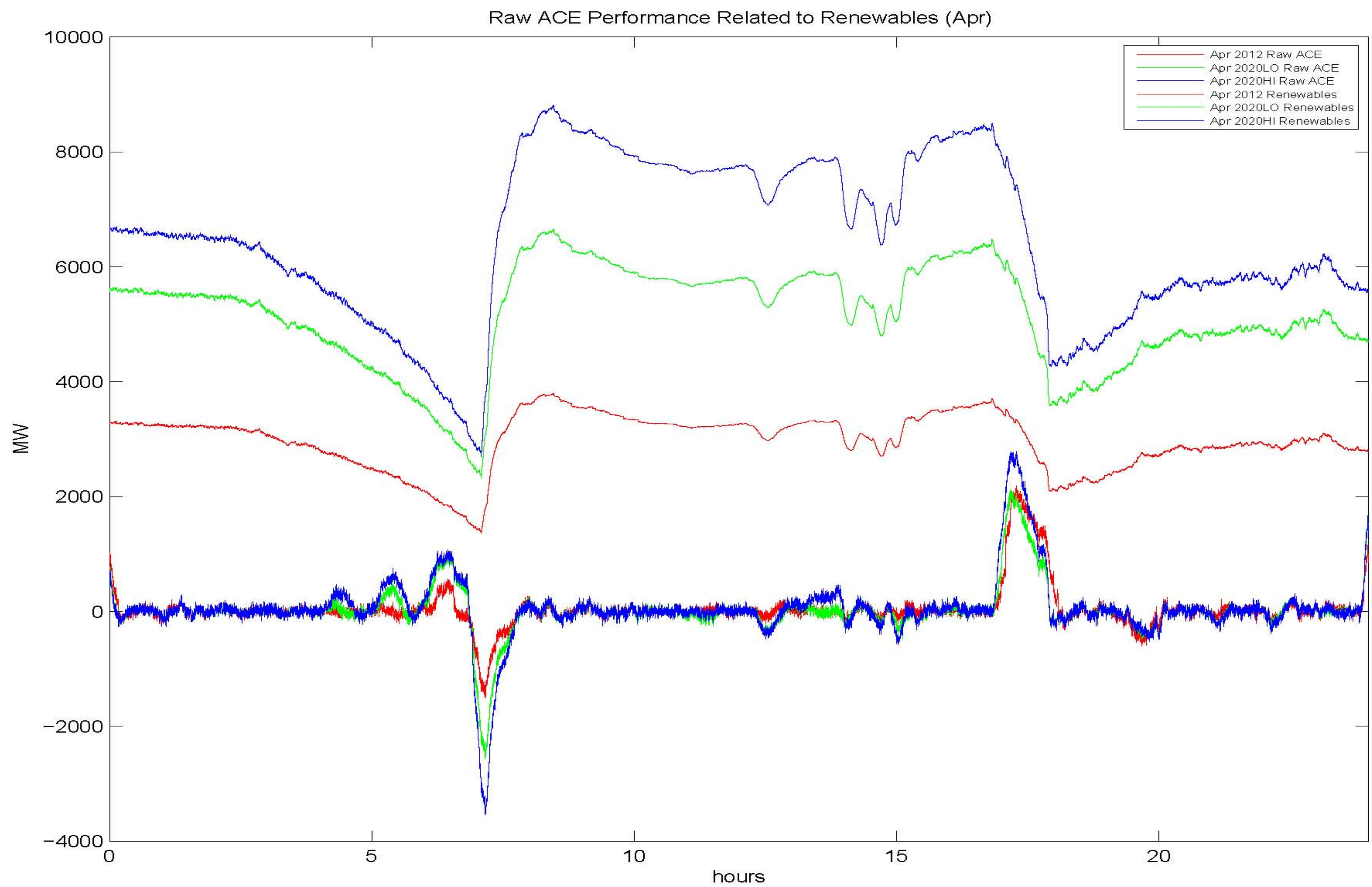
System Area Control Error (ACE)



4 Hr works

1 Hr does not work

April Day – ACE



Adjusting Conventional Generation Schedules for the 2012 and 2020 Cases

- Some conventional plants must be decommitted in hourly schedules
  - Each MW from renewables would mean 1MW less from conventional plants
  - Plan A: use results from CAISO/Nexant production costs study. (not available in study time frame)
  - Plan B: "Poor Man's Decommit"
    - Of the 250 plants modeled, we have ranked them by age and by type.
    - Plants are decommitted based on the priority list. ("Least efficient" units would go first.)
  - Some plants will be retired anyway. (per preliminary list of scheduled retirements)
  - Different cases / scenarios "re-commit" Combustion Turbines (or any other class of unit selectively) to provide ramping / regulation at specified level
  - New schedules "sanity checked" against scheduled imports, renewables, and load to ensure balance

Comment: Scheduling / De-commitment process is NOT for best economics but to study system dynamics; precise economics not a requirement for this study

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Major Conclusions

- System Requirements for “Normal” (non-ramping) periods
  - > 800 MW regulation in 2012
  - Approximately 1,600 MW in 2020
  - Storage more effective in smaller incremental amounts
- In the 2020 33% High Renewable Capacity Case the System may Require 3000 – 4000 MW of Regulation & Reserves
  - Even so, performance will not be acceptable by today’s standards
  - Requires further investigation of renewable scheduling for certainty
  - System appears to have adequate ramping capability in CT & Hydro but wind / solar scheduling vs. conventional generation is a major difficulty
  - Performance will be sensitive to 15 – 30 minute errors in renewable forecasting
- 3000 MW / 6000MW of Storage will Suffice (except possibly for the April day studied)
  - Preserves current levels of performance with respect to ACE, Frequency, CPS1
- Storage Requires an Aggregate Ramping Capability of 0 – 100% in 5 minutes in the 33% scenario
  - May indicate limited effectiveness of pumped hydro and CAES

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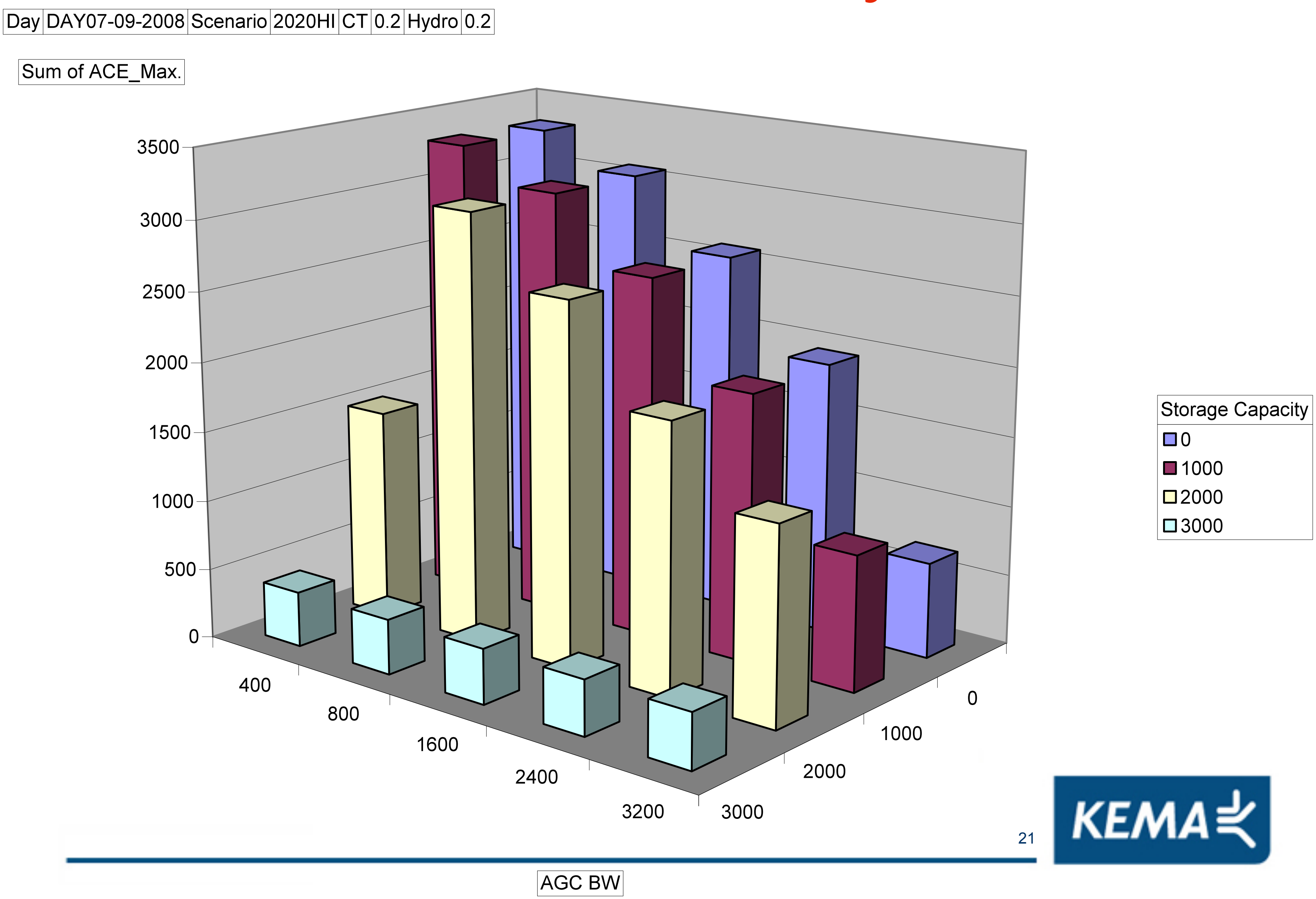
Major Conclusions (2)

- Storage equivalent to 110 MW Combustion Turbine appears to range between 30 – 50 MW of storage
  - Varies with other system conditions especially how much regulation is present
- Use of Combustion Turbines for increased regulation (forced commitment) increases overall system emissions by approximately 3% vs. using storage

System performance with storage and increased regulation during non-ramping hours

Scenario	Added Amount (MW)		Worst Maximum Area Control Error (MW)		Worst Frequency Deviation (Hz)		Worst Control Performance Standard 1 (percent)	
	Regulation	Storage	Regulation	Storage	Regulation	Storage	Regulation	Storage
20% RPS*	400	200	477	311	0.0470	0.0438	184	195
33% RPS* Low	800	400	480	493	0.0610	0.0609	190	190
33% RPS* High	1,600	1,200	480	344	0.0610	0.0590	191	196

ACE maximums for July 2020HI



Adding Storage for Normal Operations

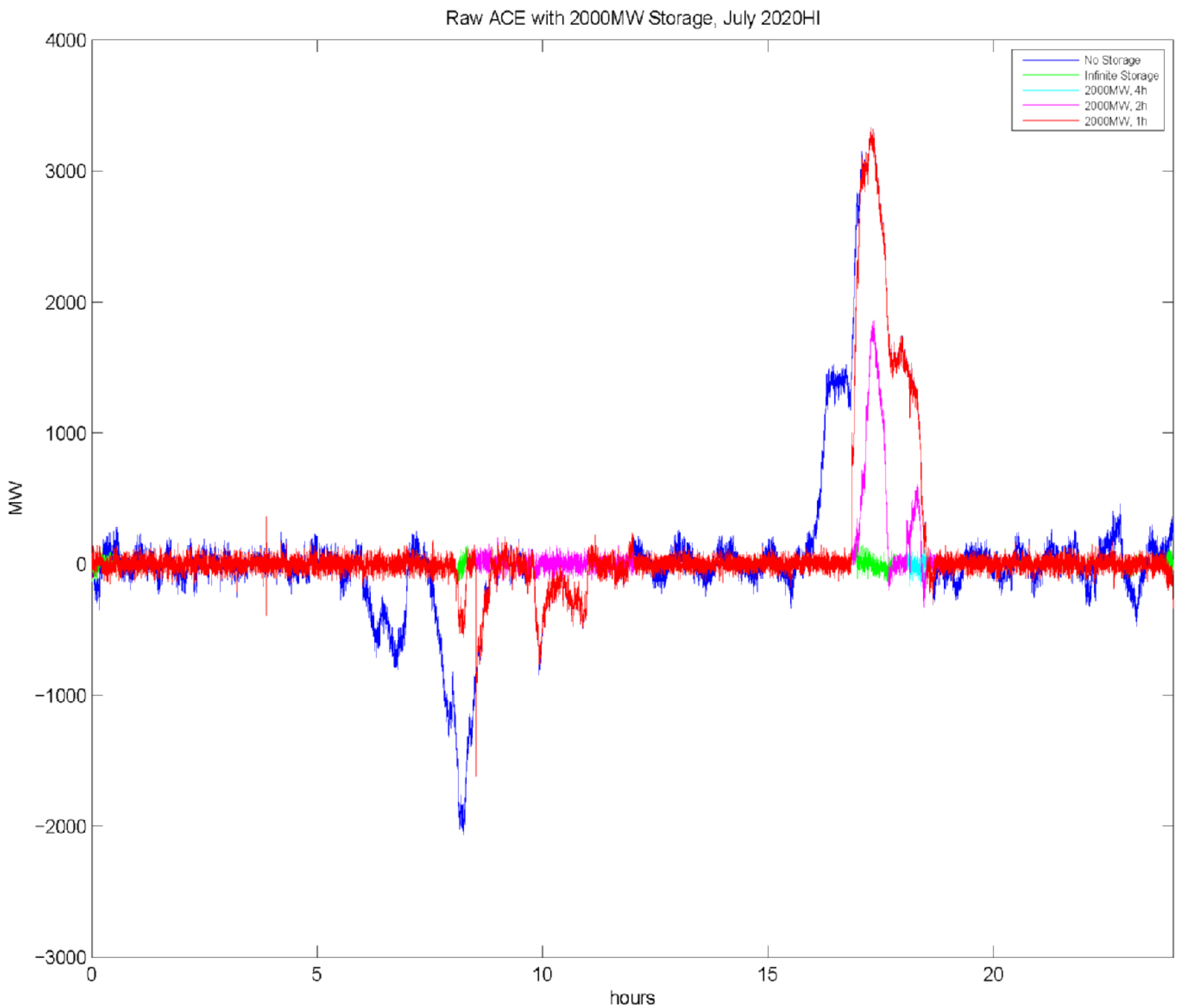
	Performance Across Regulation Levels With No Storage				Storage Added to 400 MW Regulation			
Year	Regulation	worst max ACE	worst dF	worst CPS1	Storage Added	worst max ACE	worst dF	worst CPS1
2012	400	477	0.047	184	200	311	0.0438	195
2012	800	325	0.0425	195				
2012	1600	316	0.0424	196				
2020 LO	400	690	0.063	173	400	493	0.0609	190
2020 LO	800	480	0.061	190				
2020 LO	1600	480	0.061	194				
2020LO	2400	480	0.061	194				
2020 HI	400	950	0.062	141	1200	344	0.059	196
2020 HI	800	662	0.061	172				
2020 HI	1600	480	0.061	191				
2020 HI	2400	382	0.061	191				
2020 HI	3200	382	0.061	191				

200 MW Storage > 400 MW Regulation

400 MW Storage = 400 MW Regulation

1200 MW Storage > 2400 MW Regulation

Evaluating Storage



2000 MW of storage with 4 hours of energy solves the problem.

2000 MW with 2 hours of energy helps

2000 MW of storage with only 1 Hr of energy does not control the ACE problem.

Policy Recommendations

- Use fast storage for regulation, balancing, and ramping either as a system resource to address aggregate system variability or as a resource used by renewable resource operators to address individual resource variability and ramping characteristics
- Procurement of increased regulation, balancing, and reserves by the California ISO
- Consider possible imposition of requirements on renewable resources to accommodate their effects on grid operation, such as ramp rate limits on renewable resources, more accurate short-term forecasting, sub-hourly scheduling, and other possibilities
- Pursue changes to the market system to encourage fast ramping by conventional generation resources
- Use demand response as a ramping/load following resource, not just a resource for hourly energy in the day-ahead market or for emergencies

Study Strengths & Weaknesses

Strengths:

- Detailed High Fidelity System Dynamic Model
- Calibration to CA ISO Data
- Ability to investigate the interaction of renewables, scheduling, dispatch, regulation, droop
- Development of algorithms for renewables and storage integration
- Runs 24 Hrs in approx 15 minutes
- Extensive post processing analysis capabilities

Weaknesses:

- Only a few representative days studied
- Real Time Dispatch / Balancing was old BEEP rather than MRTU
  - Some look-ahead embedded
- Conventional Unit response capabilities "optimistic"
  - Follow dispatch at rate limit promptly; regulation through full range
- "Perfect" Renewables Forecasts
- Concentrating Thermal Solar data based on two existing plants

Goal – Understand Renewables' Impact on Grid Operations

- Understand variability and volatility of Renewables – esp CST and PV
- Understand characteristics and potential of ADR
- How to forecast better – day ahead, hour ahead, intra hour
- How to factor renewable variability/volatility in dispatch and how to use storage and ADR
- What resource capabilities (storage, ADR) are needed to manage renewables
- How to distribute volatility management across time frames and products
- Understand Requirements of AGC to manage Renewables and Use ADR and Storage
- Develop and test AGC Algorithms
- What monitoring, command, and control over new resources is required?
- Understand requirements of AGC to manage Renewables and use ADR and storage
- Develop and test AGC algorithms
- What monitoring, command, and control over new resources is required?

What are Priorities for Future Work?

Develop dynamic models of CST and CSP / utility scale PV

Develop statistical description of variability with temporal and spatial correlations

Develop consensus forecast

Develop models of distributed PV and ADR for use in load disaggregation

Incorporate Renewable Variability, Storage characterizations, and ADR characteristics in Day Ahead Scheduling and Real Time Dispatch

Develop realistic scenarios of conventional unit performance for simulation

Integrate ADR, updated renewables and storage models

Install KERMIT at CA ISO and deliver training

Develop AGC Algorithms and Test

Identify “scenarios” for future portfolio and use in 2012 and 2020 studies

Integrate production cost / market simulations as inputs to KERMIT

Use KERMIT to iterate with production and market simulations around ancillaries requirements

Study impacts of forecasting accuracies

Conclusions

- Frequency Responsive Load (or Storage / Autonomous DR) is of benefit
  - Will be of greatest benefit in an island situation
- Using fast resources in response to ACE is better than response to frequency (assuming similar time constants and control/ communications) especially in terms of controlling tie flows resulting from generation/load imbalance
- Best choice of control will depend upon the situation and the problem being addressed
  - Autonomous frequency response has the virtue of requiring no control / communications